


ILLINOIS STATE GEOLOGICAL SURVEY



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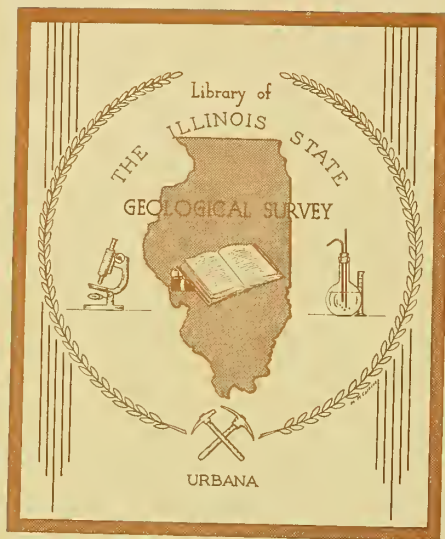
TRACE ELEMENTS IN BOTTOM
SEDIMENTS FROM UPPER PEORIA
LAKE, MIDDLE ILLINOIS RIVER
—A Pilot Project

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TRACE ELEMENTS IN BOTTOM SEDIMENTS FROM UPPER PEORIA LAKE, MIDDLE ILLINOIS RIVER—A PILOT PROJECT

Charles Collinson and Neil F. Shimp

ABSTRACT

A preliminary study of the chemical composition of bottom sediments from Upper Peoria Lake was made on samples taken from eight sites in the lake, which is an impoundment of the Illinois River near Peoria. The samples were subjected to analysis by X-ray fluorescence, neutron activation, optical emission, atomic absorption, radiochemical preparation techniques, and wet chemical methods.

Major constituents determined were silicon, aluminum, iron, magnesium, calcium, potassium, inorganic carbon, and organic carbon. Titanium, manganese, sodium, phosphorus, and sulfur were found in smaller amounts. Trace elements measured were lead, zinc, cadmium, copper, nickel, boron, chromium, beryllium, vanadium, cobalt, mercury, arsenic, bromine, lanthanum, and scandium.

Sieve and pipette analyses revealed that the sediments are sandy and clayey silts. X-ray diffraction indicated an illite-kaolinite-chlorite mixed-lattice clay fraction.

The results showed that Upper Peoria Lake bottom sediments contain more lead, zinc, and chromium than previously studied surficial sediments from southern Lake Michigan, but that they have lower levels of arsenic and bromine. Concentrations are directly related to organic carbon content and, to some extent, to the less than 2-micron clay fraction. Both organic carbon and clay fractions increase southward in Upper Lake Peoria and are larger in the navigation channel than in the shallows. Turbidity appears to have an inverse relation to trace element concentration.

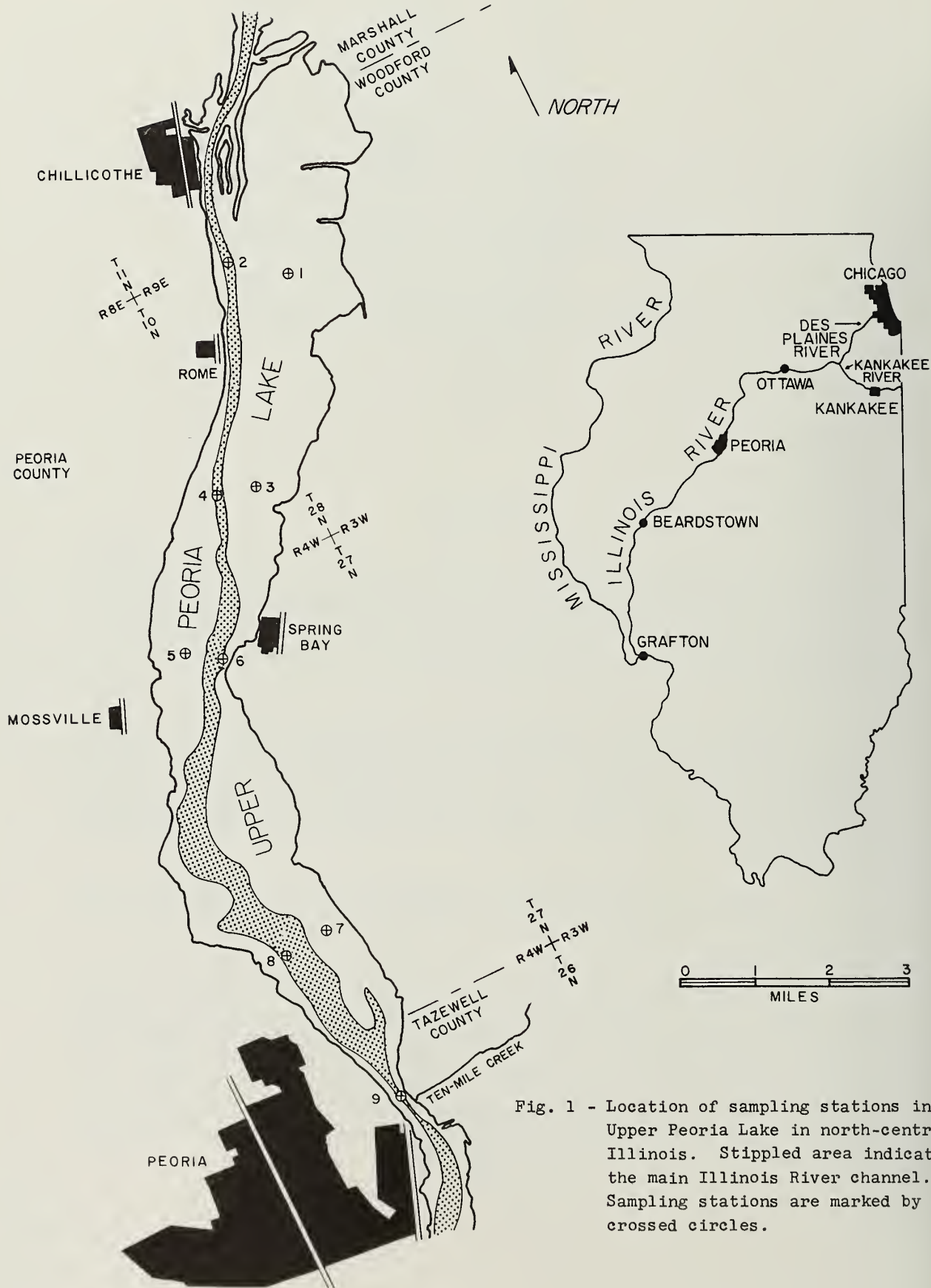


Fig. 1 - Location of sampling stations in Upper Peoria Lake in north-central Illinois. Stippled area indicates the main Illinois River channel. Sampling stations are marked by crossed circles.

INTRODUCTION

Little is known of the inorganic trace-element composition of sediments in the rivers of Illinois, although much of the state's population resides along its watercourses and the potential hazards of heavy-metal pollution of its waters and sediments are widely recognized. Little more is known about the capacity of river sediments to adsorb or otherwise accumulate trace elements and, more importantly, to return them to solution or suspension when favorable equilibrium conditions exist.

It is common knowledge, however, that stream contaminants in suspension or solution do not necessarily flow to the sea but may be altered to other compounds, may settle onto the bottom, may be ingested by plants and animals, or may be adsorbed by sediment in the stream or in its banks and bottom (Black, 1942; Coleman, 1949a, b). The fact that relatively unpolluted stretches of stream still exist in the lower reaches of the Illinois River, despite the sanitary and industrial wastes introduced into it upstream, suggests that a significant portion of the contaminants in the river do not travel far from their source but are fixed onto the sediments, which contain vast areas of adsorptive surface and act as a chemical sink. The sediments then may remain in situ or may be remobilized by currents and moved farther downstream.

Since mid-1969, Illinois State Geological Survey scientists have been probing the floor of southern Lake Michigan to determine the geologic nature of lake sediments (Gross et al., 1970; Lineback, Ayer, and Gross, 1970; and Lineback and Gross, *in press*). Survey chemists have also investigated the extent of accumulation of inorganic elements in Lake Michigan sediments (Shimp, Leland, and White, 1970; Ruch, Kennedy, and Shimp, 1970; Schleicher and Kuhn, 1970; Shimp et al., 1971; Kennedy, Ruch, and Shimp, 1971). Results showed that significant concentrations of lead, bromine, zinc, chromium, copper, arsenic, and mercury have become fixed in the bottom sediments of the lake. The studies also indicated that concentrations of these elements are highest in organic-rich, fine-grained surficial sediments, such as are common in our rivers, and that heavy metals such as arsenic and mercury are concentrated in relatively high levels in lake sediments off the mouths of rivers that drain industrialized regions.

In view of these findings, the need for analytical studies of the bottom sediments in Illinois rivers and reservoirs is obvious. Consequently, a pilot program for the systematic study of river bed and bank sediments was begun in the fall of 1970 with preliminary sampling in the Des Plaines and Kankakee Rivers, followed by sediment sampling at water quality monitoring stations of the Illinois Water Survey in Upper Peoria Lake (fig. 1).

This report presents an evaluation of preliminary data gathered from the Upper Peoria Lake study and serves as a pilot for what is hoped will be a systematic study of Illinois river sediments. Goals for such a program would include the quantitative analysis of chemical constituents in the state's river sediments, the determination of natural base levels for most trace elements, the identification of adsorptive sediments, and the establishment of a system for the identification and mapping of significant chemical concentrations in sediments.

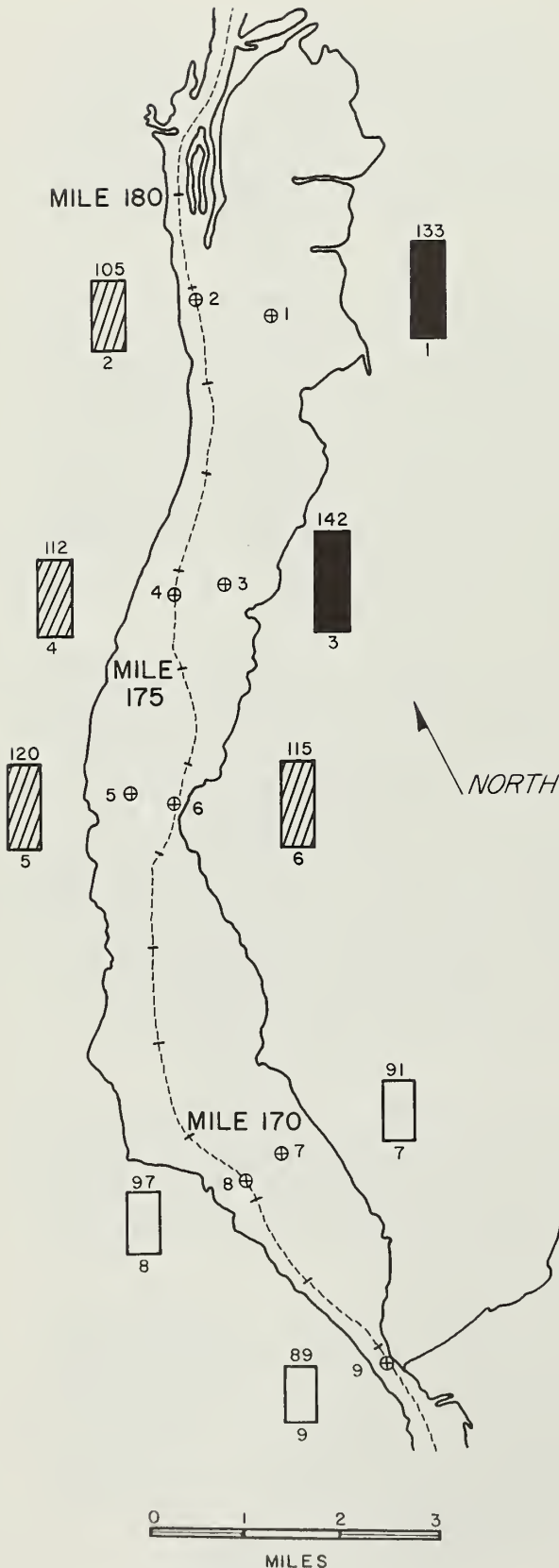
Acknowledgments

Thomas A. Butts of the Illinois State Water Survey's laboratory at Peoria kindly provided precise Illinois Waterway Chart locations of water quality sample stations in Upper Peoria Lake. John A. Wert assisted in the collection of the samples. John A. Schleicher, John K. Kuhn, Leonard R. Henderson, Joyce Kennedy Frost, and David B. Heck made the chemical analyses. Cheryl W. Adkisson supervised grain size analyses of the sediments, and H. D. Glass identified the clay mineral fractions.

PEORIA LAKE

Peoria Lake, a 13-mile long impoundment of the slow-flowing Illinois River near Peoria, has special significance for the ecology, siltation, and pollution levels in the Illinois River (Wang and Brabec, 1969; Starrett, 1971). The river has for decades received wastes from municipal and industrial areas along its banks and carried them to the Mississippi River at Grafton. Peoria Lake, 55 miles downstream from any large population center, has served as a partial recovery zone since its formation more than 35 years ago. In the lake, nitrogen levels of the river fall, turbidity is greatly reduced, and oxygen levels rise sharply (figs.

Fig. 2 - Distribution of turbidity in Peoria Lake (taken from Wang and Brabec, 1969). The number above each bar represents the mean value for turbidity in Jackson Turbidity Units. Numbers below indicate sampling stations. Shading indicates degree of turbidity. Turbidity appears to have indirect inverse relations to trace-element concentrations in the sediments (cf. fig. 5).



2 and 3). The lake has been the subject of numerous studies of water quality by the Illinois State Water Survey (Wang and Brabec, 1969; Wang and Evans, 1969, 1970; Sullivan and Hullinger, 1969; Stall and Hiestand, 1969; Ackermann, 1971), the United States Geological Survey (1967), and the Illinois State Sanitary Water Board (1967).

The effects of pollutants on bottom faunas in the Illinois River, including Peoria Lake, have been well documented by the Illinois State Natural History Survey (Richardson, 1921, 1928; Mills, Starrett, and Bellrose, 1966; and Starrett, 1971). In addition, Mathis and Cummings (1971) of Bradley University recently published chemical data on the water, fauna, and sediments of the middle Illinois River, including two sediment sites in Peoria Lake. The geology of the lake's shores has just been described by Willman and Lamar (in preparation) of the Illinois State Geological Survey.

Peoria Lake is located in a broad, relatively deep part of the Illinois River Valley, which dates from middle Pleistocene time and was later essentially filled with nearly 100 feet of alluvial gravel, sand, silt, and clay. The shores are low-level Pleistocene gravel terraces, alluvial fans of silt and silty clay, and modern alluvium consisting of silt and sandy silt.

The present lake formed from the impoundment of water behind the Peoria Lock and Dam, located at river mile 157.6 (river miles are shown on figs. 1 and 3), a short distance south of Peoria. However, before construction of the dam, a smaller but very similar natural lake had formed when the river was partly blocked by alluvial deposits from Farm Creek (river mile 162).

The present lake consists of two very shallow bodies approximately 2 to 12 feet deep—Lower Peoria Lake, which extends approximately $3\frac{1}{2}$ miles north from river mile 162.5, and Upper Peoria Lake (sometimes divided into Middle and Upper Peoria Lakes at Blue Creek Point, river mile 173.4), which extends more than 15 miles north to river mile 182 at Chillicothe. The upper and lower lakes are divided at "the Narrows," a 750-foot wide passage near Peoria Heights (about river mile 166.7). Lower Peoria Lake at its maximum is $1\frac{3}{8}$ miles wide near its southern end, whereas Upper Peoria Lake is more than 2 miles wide at its northern end.

Upper Peoria Lake is heavily turbid (fig. 2; Wang and Brabec, 1969), acting as a settling basin for the 50 miles of river below the Starved Rock Lock and Dam near La Salle (river mile 231.0). River currents of 0.9 mile per hour have been measured at the Narrows (Starrett, 1971), but commonly no current is perceptible in the open parts of the lake. Current speeds in the river proper, above and below Peoria Lake, commonly range between 0.2 and 1.7 mph at normal river stages.

Sediment generally moves very slowly through Upper Peoria Lake, which has an estimated water travel time of up to 1 day at low flow and less than half a day at high flow (Stall and Hiestand, 1969). The bottom is relatively uniform, consisting mainly of sandy and clayey silts. Starrett (1971, p. 272-273) reported the presence of a hard bottom overlain by a "false" bottom of flocculated sediment that is periodically resuspended by towboats and

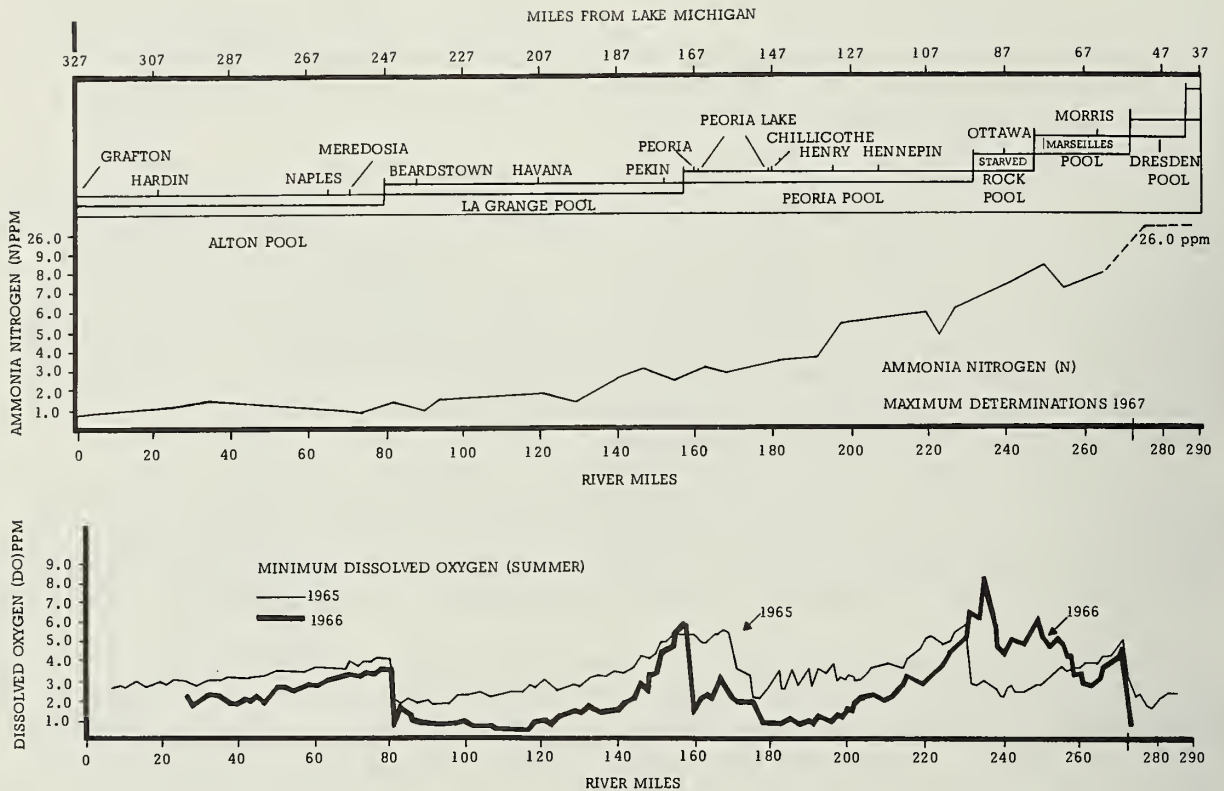


Fig. 3 - Maximum amounts of ammonia nitrogen and dissolved oxygen in the Illinois River (after Starrett, 1971, fig. 11).

temporary currents. The same author (1971, p. 272) attributed the increasing sluggishness of the river to increased planting of row crops in the watershed, a practice that, during the past 40 years, has greatly increased siltation. Stall and Melsted (1951) quoted a study of Lake Chautauqua, on the Illinois River near Havana, which showed an 18.3 percent decrease in storage capacity in 23.8 years. Such data tend to indicate that most of the sediment in the middle Illinois River impoundments has been trapped during recent years and that the sediments studied here, which came from shallow depths, may be very young. The Peoria Dam was completed in 1938, and it is probable that a blanket of fine silt and clay has since buried and overlapped the natural lake deposits. The channel is a possible exception because it has been kept open by dredging.

Wang and Brabec (1969) noted that Upper Peoria Lake water contains high concentrations of nitrogen, phosphorus, and fluorides. The last two are derived mainly from sewage and industrial wastes, whereas nitrogen comes from agricultural runoff as well. In 1963, the U.S. Public Health Service reported the following amounts of toxic metals in water samples from the Illinois River: copper, 30 parts per million (ppm); nickel, 0.01 ppm to 0.25 ppm; zinc, as much as 0.13 ppm; and chromium, 0.01 ppm to 0.08 ppm. Ackermann (1971) published the following maximum concentrations reported from river water at Peoria between 1966 and 1971: copper, 0.03 milligrams per liter (mg/l); nickel, < 0.05 mg/l; zinc, 0.14 mg/l; and chromium, < 0.005 mg/l. Mathis and Cummings (1971) reported the following maxima for Illinois River water near Peoria during the

summer of 1969: copper, 5.2 parts per billion (ppb); nickel, 6.0 ppb; zinc, 610 ppb; chromium, 38 ppb. The conclusion is that the quality of water with respect to trace elements in the Illinois River at Peoria has improved greatly during recent years.

PREVIOUS WORK

In 1967, Wang and Brabec (1969) of the Illinois State Water Survey established nine water sampling stations in Upper Peoria Lake (fig. 1). Two stations, one in the channel and one in the shallows, were chosen for each of four transections approximately perpendicular to the current flow. Water samples were collected at intervals of one to two weeks from a depth of 2 feet at all stations, and the turbidity of each sample was measured. Figure 2 summarizes the results of the study and illustrates the distribution of relative turbidities in the lake. The conclusions most important to the present study are: (1) stations in the channel tend to be more turbid than stations in shallow water at high flow, but the reverse is true at low flow; and (2) water is less turbid downstream because of its increased depth and because some settling has taken place upstream.

Wang and Brabec's stations were used for several subsequent studies. In 1969, Sullivan and Hullinger used them for an 8-month study of the phosphate budgets in Upper Peoria Lake. They found that 17 percent of the net phosphate entering the lake is retained there and suggested mechanisms that caused the retention. Of particular significance for the present study is the reported downstream decrease in total, dissolved, and particulate concentrations of orthophosphate, polyphosphate, and organic phosphate in the lake water. In addition, values for total dissolved phosphate, unlike turbidity values, were higher in the shallows than in the channel but were parallel to the trace element concentrations of the sediments examined in our study. Furthermore, they found the percentage of dissolved phosphorus in the water increased downstream, whereas the percentage of particulate phosphorus decreased.

Later the same year, Wang and Evans (1969) used the original stations to measure variations in silica and diatoms in Upper Peoria Lake. They established seasonal patterns of diatom and silica distribution in the lake and found the concentration of free dissolved silica was lower downstream. They related the reduction of silica content to absorption by diatoms, which settled to the bottom.

In 1970, Wang and Evans reported the behavior of iron in the Upper Peoria Lake, again using the established stations. They found iron was mainly particulate and its concentration was much greater upstream than down. They also established a direct correlation between iron and turbidity and recognized significant correlations between particulate Fe^{+3} , particulate Fe^{+2} , particulate silica, and particulate phosphate. A channel-shallows pattern was also discovered wherein iron fractions tend to be larger in the shallows than in the channel.

Other reports have provided data on the pollutants in faunas and bottom sediments of the Illinois River. Starrett (1971) traced the river's history of siltation and pollution from the opening of the Chicago Sanitary and

TABLE 1—DESCRIPTION OF SEDIMENT SAMPLES FROM UPPER PEORIA LAKE

Sta- tion	Depth (cm)	Kind of sample	Lithology	Water depth (ft)	Channel or nonchannel	Location	Comments
1	0-10	Core	Clayey silt	2	Nonchannel	NW SW SW NE Sec. 17, T 28 N, R 3 W, Woodford Co.	
2	0-5	Core	Clayey silt	9	Channel	SW NE NE Sec. 32, T 11 N, R 9 E, Peoria Co.	
2	5-10	Core	Clayey silt	9	Channel	SW NE NE Sec. 32, T 11 N, R 9 E, Peoria Co.	
3	0-15	Composite	Clayey silt	7-8	Nonchannel	SE NE NW SE Sec. 25, T 28 N, R 4 W, Woodford Co.	Clam shells
4	0-5	Core	Clayey, sandy silt	9	Channel	SE SW SE SW Sec. 7, T 10 N, R 9 E, Peoria Co.	Clam shells
4	5-10	Core	Clayey, sandy silt	9	Channel	SE SW SE SW Sec. 7, T 10 N, R 9 E, Peoria Co.	
5	0-10	Composite	Clayey silt	3-4	Nonchannel	SE NE SE SE Sec. 23, T 10 N, R 8 E, Peoria Co.	
6	0-5	Core	Clayey silt	9	Channel	NE NE SW SW Sec. 2, T 27 N, R 4 W, Woodford Co.	Clam shells
6	5-10	Core	Clayey silt	9	Channel	NE NE SW SW Sec. 2, T 27 N, R 4 W, Woodford Co.	
7	0-5	Core	Clayey silt	9	Nonchannel	SE NE NW SE Sec. 27, T 27 N, R 4 W, Woodford Co.	Finely broken shell material
7	5-10	Core	Clayey silt	9	Nonchannel	SE NE NW SE Sec. 27, T 27 N, R 4 W, Woodford Co.	
7	10-15	Core	Clayey silt	9	Nonchannel	SE NE NW SE Sec. 27, T 27 N, R 4 W, Woodford Co.	
7	15-20	Core	Clayey silt	9	Nonchannel	SE NE NW SE Sec. 27, T 27 N, R 4 W, Woodford Co.	
8	0-5	Core	Clayey silt	9	Channel	SW NE NE NW Sec. 14, T 9 N, R 8 E, Peoria Co.	Considerable plant debris
8	5-10	Core	Clayey silt	9	Channel	SW NE NE NW Sec. 14, T 9 N, R 8 E, Peoria Co.	
9	0-10	Composite	Sand	9	Channel	NW SW SE NE Sec. 26, T 9 N, R 8 E, Tazewell Co.	Sand composition unsuitable for trace element analysis

Ship Canal in 1900, through construction of the vast Chicago sewage treatment plants in the 1920s, the building of the locks and dams in the 1930s, and the slow recovery of the river in the 1960s and 1970s. He included considerable detail on the Peoria pool and Peoria Lake.

Mathis and Cummings recently reported (1971) on the relation between selected concentrations of heavy metals in water, bottom sediments, clams, tubificid annelids, and fish from the river near Peoria. The project used five sampling stations, the lowest at river mile 158, approximately 5 miles below Peoria. The others were at river miles 159.6 (half a mile below Peoria), 161.1 (near the southern part of the city), 163.8 (at the south end of Peoria Lake), and 167.0 (at the south end of Upper Peoria Lake). Bottom sediments were collected with a Peterson dredge in mid-river and near shore. The samples—water, animals, and sediments—were analyzed with an atomic absorption spectrophotometer for copper, nickel, iron, calcium, lead, chromium, potassium, magnesium, lithium, sodium, zinc, cobalt, and cadmium.

Mathis and Cummings also investigated trace element concentrations in sediments from three nonindustrial streams: Jubilee Creek, Kickapoo Creek, and Lamarck Creek—all near Peoria. Ranges of the nonindustrial stream concentrations were all within the limits of the Mathis and Cummings Illinois River sediment concentrations, and most were below values for Upper Peoria Lake. Our interpretation of their figures is that the nonindustrial ranges probably indicate the approximate bottom sediment base levels that could be expected at Peoria in a nonpolluted Illinois River.

Mathis and Cummings discovered several important relations between concentrations in bottom sediments, animals, and water. They showed that heavy metal concentrations in the bottom-dwelling clams and tubificid annelids are very close to those measured in the sediments but are considerably lower than those in herbivorous fishes and much lower than those in carnivorous fishes.

Comparison of the Mathis and Cummings values for mean concentration of metals in Illinois River water with their mean concentration in the sediments provides the following approximate ratios: copper, 1:100; nickel, 1:10; lead, 1:14; chromium, 1:10; cobalt, 1:8; cadmium, 1:5; and zinc, 1:12. With more and refined data, such figures might be used for estimating concentrations of metals in the depositing waters of old, now dry, sediments and might also provide a basis for estimating concentrations to be expected in stream sediments when composition of the water as well as grain size and organic content of the sediment are known.

COLLECTION OF BOTTOM SEDIMENTS FROM UPPER PEORIA LAKE

The bottom sediment samples used in our study were collected in June 1971 when the river was at normal stage and no unusual conditions prevailed. Collection was made at Wang and Brabec's (1969) original nine stations. Location of the stations, depths of samples below the lake floor, and descriptions of the sediments are summarized in table 1. Samples taken in the channel appeared to be more cohesive than those taken in the shallows. The percentages of sand, silt, and < 2 μ clay fractions in the samples are shown graphically in figure 4.

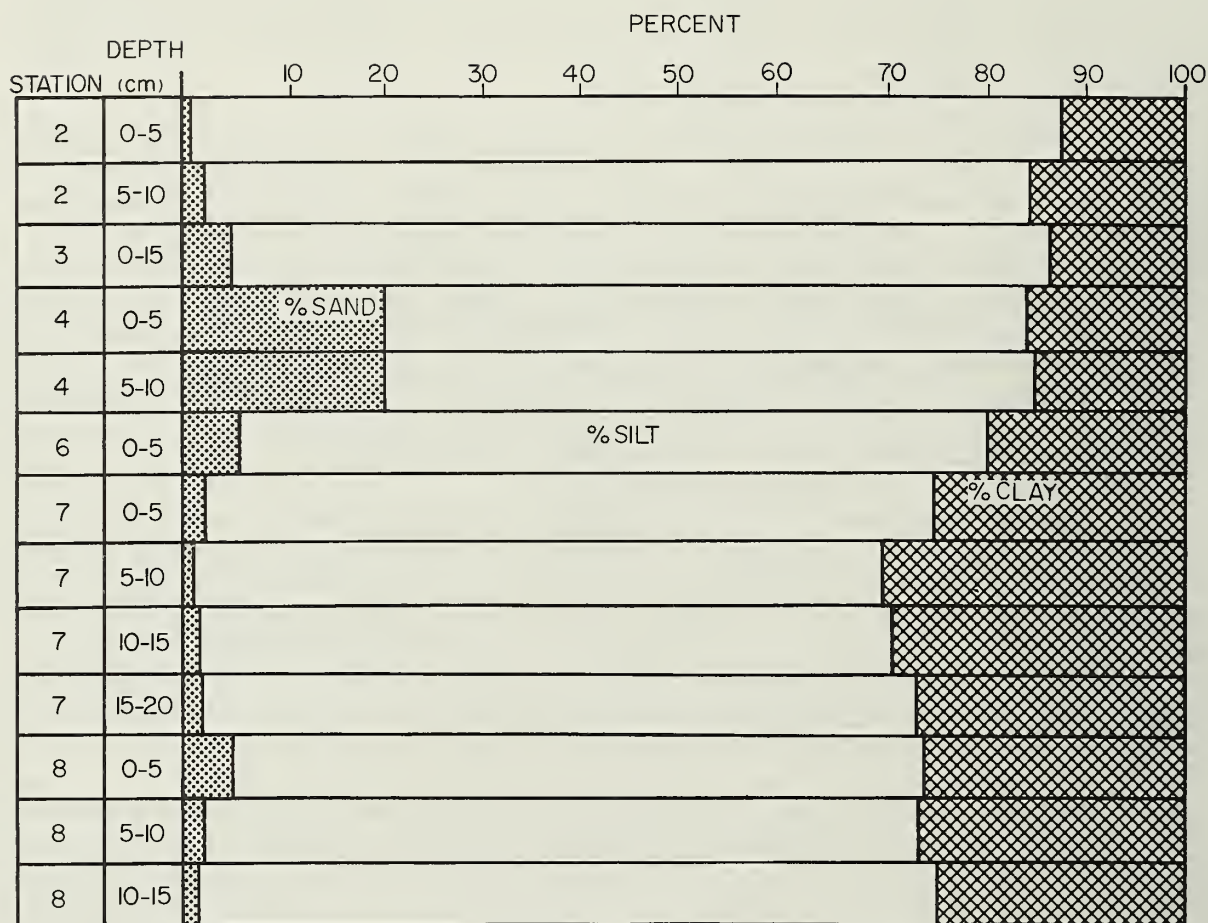


Fig. 4 - Percentages of sand, silt, and $< 2 \mu$ clay in sediment samples from bottom of Upper Peoria Lake.

Samples from Stations 2 through 4 and 6 through 9 were obtained with a modified Ponar dredge operated from a 23-foot cruiser equipped with winch, work platform, recording fathometer, pelorus, and dry ice chest. Samples at Stations 1 and 5, where stumps and muddy shallows prevented passage of the larger boat, were taken with a long handled scoop from an inflatable dingy in water depths of 2 feet and $3\frac{1}{2}$ feet, respectively.

The Ponar dredge had been modified by Collinson, who added hinged removable doors and ground the jaw faces to prevent disturbance of the sediment surface or the loss of sediment by washout. The samples obtained were essentially undisturbed, and up to 20 cm of sample was recovered at Station 7. On deck, the dredge doors were removed and a plastic CAB tube 2 inches in diameter was pressed into the sediment and withdrawn containing the sediment core. The core was extruded and cut into 5 cm subsamples, which were sealed in plastic bags and placed in the cooler. The samples were kept below 4°C until dried in the laboratory prior to chemical analysis.

PHYSICAL ANALYSES

Sand and silt fractions in the sediments were determined by standard sieve analysis. The less than 2-micron clay fraction was determined by conventional pipette analyses. The results are shown in figure 4. The samples from Station 9 in the Narrows was mainly sand and silt with very little clay and was unsuitable for trace element analysis. In general, the sand fraction decreases downstream. The clay fraction increases downstream, whereas silt remains relatively constant.

Clay mineralogy of selected samples was determined by X-ray diffraction analysis of the less than 2-micron fraction. The total clay fraction was expressed as percentages of three clay mineral assemblages: expandable clay minerals, illite, and kaolinite plus chlorite. Expandable clay minerals here include montmorillonite and mixed-layered and degraded clay minerals that expand to approximately 17 angstroms after treatment with ethylene glycol.

The clay fraction proved to be of essentially the same composition for all samples, averaging 30 percent expandable minerals (range of 23 to 38 percent), 52 percent illite (range of 46 to 59 percent), and 18 percent kaolinite plus chlorite (range of 16 to 20 percent). The composition probably reflects an origin in the weathered Bloomington and Metamora tills of the region and minor amounts of Woodfordian loess.

CHEMICAL ANALYSES

Methods of analysis used on the samples have been described by Shimp, Leland, and White (1970).

Aluminum, silicon, iron, calcium, magnesium, potassium, titanium, manganese, and phosphorus were determined by X-ray fluorescence and expressed as oxides. Relative precision values of ± 0.5 percent were found for SiO_2 and TiO_2 , ± 1 percent for Al_2O_3 , CaO , K_2O , and Fe_2O_3 , ± 2 percent for MgO , and ± 5 percent for P_2O_5 and MnO .

Sodium, bromine, lanthanum, scandium, and cobalt values were obtained by neutron activation techniques, which yielded values having a precision of ± 10 percent.

Beryllium, chromium, nickel, lead, and vanadium values were determined by optical emission spectrography with a precision of ± 10 to ± 15 percent.

An atomic absorption spectrophotometer with strip chart recorder was used to measure cadmium, copper, and zinc. Results had a precision of ± 10 percent. Boron was measured by a colorimetric method. Sulfur was measured by a wet chemical method, total carbon by high-temperature combustion, inorganic carbon by the common acid-evolution-gravimetric method, and organic carbon was found by difference.

Mercury content was measured by neutron activation methods with radiochemical separation (described by Kennedy, Ruch, and Shimp, 1971,

TABLE 2—TRACE ELEMENT CONCENTRATIONS (PPM) IN AIR-DRIED BOTTOM
SEDIMENTS FROM UPPER PEORIA LAKE, MIDDLE ILLINOIS RIVER

Station	Depth (cm)	Pb	Zn	Cd	Cu	Ni	B	Cr	Be	V	Co	Hg	As	Br	Ia	Sc
1	0-10	64	185	3	22	22	10	64	1.8	22	6	0.12	5	< 8	21	11
2	0-5	145	430	8	62	52	38	261	2.1	92	6	0.17	14	< 22	21	10
2	5-10	131	364	7	47	56	34	143	4.0	82	11	0.22	11	< 18	33	7
3	0-15	123	469	8	48	59	27	117	3.0	58	12	0.25	13	< 19	34	5
4	0-5	132	479	9	62	74	28	127	2.3	60	14	0.37	9	< 21	26	7
4	5-10	178	525	11	67	77	30	159	2.7	77	14	0.21	13	< 21	28	8
5	0-10	130	450	9	59	37	32	119	2.3	48	14	0.28	11	< 15	31	10
6	0-5	131	382	9	55	42	32	150	2.7	94	11	0.24	11	< 21	34	10
6	5-10	52	196	2	28	18	28	80	1.9	66	12	0.20	12	< 15	33	10
7	0-5	176	475	5	72	69	49	199	3.4	113	12	0.12	12	< 22	39	9
7	5-10	155	508	9	71	56	45	165	2.9	82	13	0.20	12	< 17	32	10
7	10-15	178	508	10	80	60	47	144	2.8	96	17	0.24	13	< 21	38	11
7	15-20	172	513	13	88	52	44	193	2.6	81	14	0.23	13	< 20	34	14
8	0-5	198	543	11	82	55	52	152	2.5	82	15	0.26	12	< 26	39	10
8	5-10	204	667	13	88	76	43	194	3.3	110	14	0.39	13	< 22	35	14

TABLE 3—CONCENTRATIONS OF MAJOR AND MINOR CONSTITUENTS IN
BOTTOM SEDIMENTS FROM UPPER PEORIA LAKE

Sta- Depth tion (cm)		Percentage of Oven-Dry Material (100° C)															Total	
		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	H ₂ O*	In. C†	Org. C	S	Ign. loss†		Min. CO ₂
1	0-10	69.0	0.38	6.37	2.61	0.046	2.20	5.74	0.90	1.74	0.53	2.33	2.09	0.71	0.03	10.73	7.66	100.25
2	0-5	60.3	0.65	11.60	4.95	0.085	2.45	4.32	0.70	2.29	0.58	5.31	1.06	2.84	0.08	12.12	3.89	99.34
2	5-10	63.7	0.61	9.23	4.12	0.068	2.49	4.65	0.82	2.11	0.56	4.05	1.32	2.12	0.06	11.06	4.83	99.42
3	0-15	60.9	0.59	10.10	4.43	0.082	2.66	5.33	0.83	2.01	0.82	3.89	1.51	2.26	0.07	11.77	5.55	99.52
4	0-5	60.9	0.47	9.22	3.10	0.084	2.84	6.12	0.90	1.85	1.17	4.09	1.86	2.66	0.09	13.64	6.80	100.29
4	5-10	56.1	0.51	9.60	4.87	0.092	2.59	7.49	0.70	2.04	1.22	4.04	1.98	3.49	0.13	14.93	7.27	100.14
5	0-10	60.7	0.60	10.90	4.31	0.086	2.78	4.92	0.86	2.14	0.68	4.75	1.37	2.38	0.07	12.22	5.02	100.20
6	0-5	58.9	0.64	12.20	5.11	0.092	2.01	5.35	0.71	2.24	0.60	5.08	1.32	2.24	0.09	12.26	4.85	100.11
6	5-10	63.0	0.65	11.60	4.73	0.072	2.21	3.70	0.79	2.31	0.18	4.35	1.09	1.39	0.03	9.78	4.01	99.02
7	0-5	57.9	0.68	12.10	5.34	0.099	2.60	4.40	0.69	2.35	0.58	5.79	1.10	2.92	0.09	12.82	4.02	99.55
7	5-10	57.9	0.68	12.20	5.30	0.076	2.48	4.50	0.70	2.39	0.67	5.48	1.14	2.81	0.10	12.55	4.16	99.45
7	10-15	57.8	0.68	12.30	5.44	0.113	2.48	4.41	0.70	2.43	0.64	5.62	1.08	2.86	0.10	12.55	3.97	99.54
7	15-20	57.3	0.65	13.00	5.52	0.094	2.46	4.31	0.65	2.50	0.62	6.06	1.08	2.72	0.10	12.74	3.95	99.93
8	0-5	56.5	0.67	13.2	5.77	0.092	2.68	4.03	0.68	2.55	0.64	6.39	0.96	3.36	0.10	13.37	3.52	100.10
8	5-10	56.8	0.64	12.4	5.67	0.084	2.45	4.47	0.71	2.34	0.91	5.46	1.12	3.32	0.09	12.96	4.09	99.44

* H₂O (+ 100 C) = ignition loss — (CO₂ + SO₃ + organic carbon).

† Not included in total.

STATION	DEPTH CM	Hg	Pb	Cu	Zn	Ni	Cr	As	Cd	Br *	MnO	S	Org. C	<2 μ CLAY
		PPM 1 2 3 4 50	PPM 100 150	PPM 25 50 75	PPM 200 400 600	PPM 20 40 60 75	PPM 150 225 300	PPM 5 10 15	PPM 7 14 20	PPM 10 20 30	% 0.05 .1 .15 .2	% 0.05 .1 .15 .2	% 1 2 3 4	% 15 25
1	0-10	.	.	.	.	.	.	.	.	.	.	.	.	.
2	0-5	.	.	.	.	.	.	.	.	.	.	.	.	.
2	5-10	.	.	.	.	.	.	.	.	.	.	.	.	.
3	0-15	.	.	.	.	.	.	.	.	.	.	.	.	.
4	0-5	.	.	.	.	.	.	.	.	.	.	.	.	.
4	5-10	.	.	.	.	.	.	.	.	.	.	.	.	.
5	0-10	.	.	.	.	.	.	.	.	.	.	.	.	.
6	0-5	.	.	.	.	.	.	.	.	.	.	.	.	.
6	5-10	.	.	.	.	.	.	.	.	.	.	.	.	.
7	0-5	.	.	.	.	.	.	.	.	.	.	.	.	.
7	5-10	.	.	.	.	.	.	.	.	.	.	.	.	.
7	10-15	.	.	.	.	.	.	.	.	.	.	.	.	.
7	15-20	.	.	.	.	.	.	.	.	.	.	.	.	.
8	0-5	.	.	.	.	.	.	.	.	.	.	.	.	.
8	5-10	.	.	.	.	.	.	.	.	.	.	.	.	.

* Values for bromine are less than those given.

Fig. 5 - Summary of selected trace element concentrations (ppm) in bottom sediments from Upper Peoria Lake and comparison with percentages of manganese sulfur, carbon, and < 2 μ clay.

p. 3-7). Arsenic was measured by radiochemical methods (described by Ruch, Kennedy, and Shimp, 1970, p. 2-3). Precision was \pm 7 percent.

DISCUSSION

Although nine bottom sediment stations in Upper Peoria Lake (fig. 1) were sampled for trace element measurement, only samples from Stations 1 through 8 were analyzed. The sample from Station 9 was not suitable for analysis. The results of the study are presented mainly in the figures and tables. Descriptions of the sediments are given in table 1, determinations of trace element concentrations appear in table 2, the chemical determinations for major and minor constituents are given in table 3, trace element accumulation in channel and nonchannel samples are compared in table 4, and trace element values from Peoria Lake are compared with those from southern Lake Michigan in table 5. Figure 2 presents turbidity measurements, figure 3 shows dissolved oxygen and ammonia values, figure 4 graphically illustrates the percentages of sand, silt, and less than 2-micron clay fraction in the samples, and concentrations (ppm) for nine of the trace elements are compared with concentrations of manganese, sulfur, organic carbon, and less than 2-micron clay in figure 5.

The sediments encountered in the study are brownish gray clayey and sandy silts that are somewhat cohesive in samples from the navigation channel but noncohesive in the shallows samples. Clam shells and plant debris are common in the sediments. The clay fraction increases appreciably southward in the lake (fig. 4), and a parallel decrease in SiO_2 , accompanied by an increase in Al_2O_3 and Fe_2O_3 , is evident in table 3.

Other trends are discernible, although too few samples were examined to permit confidence in their patterns. For example, CaO , mineral CO_2 , and Na_2O show relatively high values in the northern half of the lake, whereas Fe_2O_3 , TiO_2 , K_2O , and S show high values in the south. Such differences are probably due to subtle mineralogical variations related to the southward fining

TABLE 4—AVERAGE TRACE ELEMENT ACCUMULATION IN SAMPLES FROM CHANNEL LOCATIONS COMPARED TO ACCUMULATION IN SAMPLES FROM NONCHANNEL LOCATIONS
(C = Channel, NC = Nonchannel)

Station	Pb		Zn		Cd		Cu		Ni	
	C	NC	C	NC	C	NC	C	NC	C	NC
2 and 1	138.0	64.0	397	185.0	7.5	3	54.5	22	54.0	22.0
4 and 3	155.0	123.0	502	469.0	10.0	8	64.5	48	75.5	59.0
6 and 5	91.5	130.0	289	450.0	5.5	9	41.5	59	30.0	37.0
8 and 7	201.0	166.0	605	491.5	12.0	7	85.0	71.5	65.5	62.5
Average	146.4	120.8	448	398.9	8.8	6.8	61.4	50.1	56.3	45.1

Station	B		Cr		Be		V		Co	
	C	NC	C	NC	C	NC	C	NC	C	NC
2 and 1	36.0	10.0	202	64	3.05	1.80	87.0	22.0	8.5	6.0
4 and 3	29.0	27.0	143	117	2.50	3.00	68.5	58.0	14.0	12.0
6 and 5	30.5	32.0	115	119	2.30	2.30	80.0	48.0	11.5	14.0
8 and 7	47.5	47.0	173	182	2.90	3.15	96.0	97.5	14.5	12.5
Average	35.8	29.0	158.3	120.5	2.70	2.56	82.9	56.7	12.1	11.1

Station	Hg		As		Br		La		Sc	
	C	NC	C	NC	C	NC	C	NC	C	NC
2 and 1	0.19	0.12	12.5	5.0	< 20	< 8	27.0	21.0	8.5	11.0
4 and 3	0.29	0.25	11.0	13.0	< 21	< 19	27.0	34.0	7.5	5.0
6 and 5	0.22	0.28	11.5	11.0	< 18	< 15	33.5	31.0	10.0	10.0
8 and 7	0.32	0.16	12.5	12.0	< 24	< 19.5	37.0	35.5	12.0	9.5
Average	0.25	0.20	11.9	10.3	---	---	31.1	30.4	9.5	8.9

of the sediments, but they could also be connected with dissolved oxygen concentrations (fig. 3), which Starrett (1971, p. 344) showed to be distinctively higher in the southern half of the lake, or could be related to turbidity, values for which indicate that sedimentation rates are higher in the north than in the south.

Trace elements likewise show increases in concentration southward (fig. 5). Mercury, lead, copper, zinc, nickel, cadmium, and bromine all show relatively higher values in the southern part of the lake than farther north, an increase that seems to be directly related to organic carbon content and, to a lesser extent, to the size of the < 2-micron clay fraction. The relationship between the presence of clay and organic carbon and the concentration of trace elements in Lake Michigan sediments was clearly demonstrated by Shimp, Leland, and White (1971) and apparently is here verified for river sediments.

A distinct pattern of relatively higher trace element concentrations also is apparent in samples from the navigation channels (Stations 2, 4, 6, 8, fig. 1) when they are compared to samples from the shallows (table 4). Differences in concentrations appear to be related to distance between the channel site and the shallows site. Samples from Stations 5 and 6 do not show such clear differences, but they were taken near a constriction in the lake, and Station 5, though not in the channel, is in the direct line of flow. The differences in concentration appear to be related to age and compositional differences between the hard bottom sediments found in the channel (Starrett, 1971, p. 272-273) and sediments from the shallows, which are probably younger, less consolidated, and less polluted. Younger sediments have been removed

TABLE 5—COMPARISON OF TRACE ELEMENT CONCENTRATIONS IN SURFICIAL BOTTOM SEDIMENTS FROM UPPER PEORIA LAKE AND SOUTHERN LAKE MICHIGAN

Trace element	Upper Peoria Lake (ppm)	Lake Michigan (ppm)	Accumulations U. Peoria L./L. Michigan
As	10.0-14.0	15.00-25.0	Lower
Hg	0.1-0.4	0.05-0.4	Same
Pb	50.0-200.0	25.00-175.0	Higher (below 5 cm)
Zn	200.0-550.0	75.00-400.0	Higher
Cd	3.0-13.0	---	---
Cu	25.0-90.0	20.00-100.0	Same
Ni	20.0-75.0	20.00-60.0	Slightly higher
Cr	60.0-250.0	20.00-120.0	Higher
B	10.0-50.0	10.00-70.0	Same
Be	1.8-3.0	0.50-3.0	Same
V	50.0-100.0	20.00-80.0	Same
Co	5.0-17.0	6.00-24.0	Same
Br	< 20	10.00-130.0	Lower
La	20.0-40.0	10.00-30.0	Same
Sc	5.0-15.0	3.00-12.0	Same

TABLE 6—RANGES OF TRACE ELEMENT CONCENTRATIONS IN THE PEORIA AREA

Metal	Upper Peoria Lake (mile 167-172) (ppm)	Illinois River* (mile 158-167) (ppm)	Nonindustrial* streams (ppm)
Pb	52-204	3.0-140.0	12.9-27.1
Zn	185-667	6.0-339.0	18.0-41.0
Cd	2-13	0.2-12.1	0.23-0.56
Cu	22-88	1.0-82.0	3.5-11.2
Ni	18-77	3.0-124.0	10.0-22.2
Cr	64-261	2.0-87.0	3.4-7.4
Co	6-17	1.1-17.6	4.1-8.4

* From Mathis and Cummings (1971).

from the channel by dredging and current scour. Further study is certainly indicated.

Distribution of trace elements with respect to depth of sediment is relatively uniform (fig. 5) and quite unlike trace element distribution in bottom sediments from southern Lake Michigan where concentrations are limited to the uppermost 10 cm (Shimp, Leland, and White, 1970). Our deepest penetration in Peoria Lake, 20 cm, was at Station 7, where concentration of most elements increased slightly with depth. Concentrations also increased slightly with depth at Stations 2, 4, and 8, but they decreased at Station 6. Comparison of river concentrations with those from uppermost Lake Michigan sediments was one of our principal goals and revealed a number of interesting relations (table 5). For example, mercury values in Upper Peoria Lake were virtually the same as those encountered in Lake Michigan, but arsenic values were perceptibly lower. Only chromium and zinc had appreciably higher values than they had in Lake Michigan, whereas the bromine and the arsenic were notably lower. Further study will be required to determine whether or not the similarity of the two sets of results indicates that the maximum values represent limits of adsorption for the sediments.

Baseline values are unknown for trace elements in Peoria Lake or in the Illinois River, but values given by Mathis and Cummings for three nonindustrial streams in the Peoria area (table 6) probably approximate such levels. Our values for lead, zinc, cadmium, copper, nickel, chromium, and cobalt in Upper Peoria Lake sediments are, respectively, 3X, 16X, 26X, 8X, 3X, and 2X their nonindustrial stream values. The Mathis and Cummings ranges for trace element concentrations in Upper Peoria Lake at their Station 167.0 are compared in table 7 to our values from Stations 7 and 8 near by.

TABLE 7—RANGES OF CONCENTRATIONS IN BOTTOM SEDIMENTS
COMPARED WITH THOSE FOUND BY MATHIS AND CUMMINGS

Metal	Stations 7 and 8 (ppm)	Station 167.0* (ppm)
Pb	172-204	3.0-140.0
Zn	475-667	6.0-315.0
Cd	5-13	0.2-12.1
Cu	71-88	1.0-82.0
Ni	60-76	3.0-124.0
Cr	80-199	2.0-87.0
Co	12-17	1.1-17.6

* From Mathis and Cummings (1971).

Several problems remain to be solved. For example, determination of the reason for channel-nonchannel variations in chemical concentrations will require detailed sampling of the lake bottom, while verification of the roles of turbidity and sedimentation rates in trace element concentration necessitates sedimentation studies. Similarly, clarification of the relationship between seasonal flow, water composition, and sedimentation rates will require microstratigraphic analyses of sediment cores.

SUMMARY

The Illinois River is a slow-flowing, impounded stream that for decades has received the wastes from numerous municipal and industrial areas upstream and has conducted them to the Mississippi River at Grafton. On the middle Illinois River, 55 miles below any large population center, is Peoria Lake, a 13-mile long impoundment in which the river silts have settled for more than 50 years. The upper part of the lake (Upper Peoria Lake) is above the city of Peoria, so that pollutants associated with its sediments are those derived mainly from drainage of agricultural lands and those that persist from the cities upstream.

Core and grab samples of bottom sediments were taken for chemical analysis from 9 locations in Upper Peoria Lake. The sites were chosen because they had been used previously for studies of water quality by the Illinois State Water Survey. Six hundred chemical analyses were made to determine concentrations of 27 constituents, including lead, zinc, cadmium, copper, nickel, boron, chromium, scandium, beryllium, vanadium, cobalt, mercury, arsenic, bromine, lanthanum, sulfur, inorganic carbon, organic carbon, silicon, titanium, aluminum, iron, manganese, magnesium, calcium, sodium, potassium, and phosphorus. Grain-size analyses identified the sediments as clayey silts, and X-ray diffraction analyses indicated the clay was composed of illite, expandable clays, and kaolinite-chlorite.

When the results of the analyses are compared with those previously derived from bottom sediments in Lake Michigan and those known from water quality and biological studies in the Illinois River, they indicate that Upper Peoria Lake sediments contain less arsenic and bromine than surficial southern Lake Michigan sediments; about the same levels of mercury, cadmium, copper, boron, beryllium, nickel, vanadium, cobalt, lanthanum, scandium, and manganese; and somewhat higher levels of lead, zinc, and chromium. Similar concentrations of any given element extend throughout the entire depth of sediment sampled (up to 20 cm) in Upper Peoria Lake and are comparable to the relatively high amounts of trace elements found only in the top few centimeters (0-5) of many Lake Michigan fine-grained sediments. As in Lake Michigan, concentration levels are related to the quantity of organic carbon and < 2-micron clay present and appear to be inversely related to turbidity.

Samples taken in the navigation channel generally contain higher trace concentrations than nonchannel samples and seem to verify the presence of a poorly consolidated bottom consisting of very recent sediment contributions that are relatively low in trace element concentrations. The "false bottom" (Starrett, 1971, p. 272) is underlain by consolidated, older sediments containing relatively high trace element concentrations.

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